

PAPER • OPEN ACCESS

Elaboration of an Algorithm for the Efficient Use of Municipal Solid Waste Landfills

To cite this article: A Rummyantseva *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **317** 012007

View the [article online](#) for updates and enhancements.

ECS
The Electrochemical Society
THE KOREAN ELECTROCHEMICAL SOCIETY

**The best technical content in
electrochemistry and solid state
science and technology!**

Available until November 9, 2020.

PRIME™
PACIFIC RIM MEETING
ON ELECTROCHEMICAL
AND SOLID STATE SCIENCE
2020

**REGISTER TO ACCESS
CONTENT FOR FREE! ▶**

Elaboration of an Algorithm for the Efficient Use of Municipal Solid Waste Landfills

A Rumyantseva¹, M Berezyuk¹, I Plastinina¹ and E Rumyantseva²

¹ Department of Environmental Economics, Ural Federal University named after the first President of Russia B.N. Yeltsin, 19 Mira street, Ekaterinburg, Russia

² Department of Finance and tax management, Ural Federal University named after the first President of Russia B.N. Yeltsin, Russia

E-mail: alenarum@mail.ru

Abstract. The annual increase in generation and disposal of production and consumer wastes presents an ever pressing environmental, economic, and social challenge for modern industrially developed urbanized territories. As part of the waste management reform, an important issue is the restoration of old landfills for municipal solid waste (MSW). One of possible engineering solutions for the implementation of projects for the reburial of waste from old landfills is excavation of the landfill body with further sorting and extraction of landfill soil and, in some cases, recycled materials. This will reduce the amount of waste subject to reburial. The article examines several options for the implementation of the projects of old landfill restoration. It offers an algorithm for the efficient use of MSW landfills based on the data of environmental and economic analysis of some waste landfill restoration projects.

1. Introduction

Ensuring environmental safety is one of the priorities of the social and economic development of Russia. Despite current reforms in the sphere of the state environmental stewardship management, the problems associated with climate change, depletion of natural resources, waste accumulation and an increase in the burden of disease due to environmental pollution have remained relevant for decades.

One of the most important strategic approaches of "green" modernization is the transition to a new waste management system based on modern management methods within the framework of the circular or closed economy.

The circular economy entails the principles of rational waste management to the best advantage. It evolves a complex approach to economic activities, i.e. multiple use of material resources achieved through implementation of respective technological and organizational innovations of production processes and waste management schemes [1]. This should lead to a significant reduction of virgin raw material consumption, increase in the use of renewable resources, reduction of the need for landfill space, and improvement of the environmental quality. Waste management is therefore one of the milestones of the circular economy [2].

As per the Decree of the President of Russia No.204 *Concerning national goals and strategic objectives of the development of the Russian Federation for the period through to 2024 year*, to ensure efficient management of production and consumer waste, including elimination of all unauthorized



landfills identified as of January 1, 2018 within the boundaries of the cities, it is necessary to establish an integrated MSW management system, including elimination of landfills and restoration of the territories where they are located, provision of attractive conditions for the recycling of all production and consumer wastes prohibited for burial [3].

In contrast to industrial wastes generated within the premises of various industrial enterprises, municipal solid waste (MSW) is produced everywhere and its disposal within territorial entities of the Russian Federation is very irregular. For example, many types of waste are produced mainly in cities, but are removed and accumulated on the outskirts of settlements or adjacent territories, which determines regional and interregional specifics.

Thus, along with the development of a modern and efficient system for separate waste collection characterized by maximum level of recovery of useful components and waste processing, it is necessary to find an engineering solution for such an economically tricky challenge as restoration of old MSW landfills [4–6].

2. MSW disposal facilities: current situation

In 2017, the volume of MSW removal from urban settlements nationwide amounted to 274.4 million m³, which is 16.6% more than in 2010. The volume of MSW removed to waste sorting plants in 2017 amounted to 27.9 million m³, or 10% of the total MSW volume. Geographically, the largest volume of removed MSW in 2017 was recorded in the Central Federal District (30%), while the smallest – in the North Caucasian Federal District (3%). Burial is the main method of the waste management in the Russian Federation. In 2017, the volume of the MSW removed to burial facilities amounted to 87% of the total MSW removal. In 2017, 2.2% of the total MSW were removed for neutralization, including removal to waste incineration plants [7]. The dynamics of MSW production and use in the Russian Federation is given in Figure.

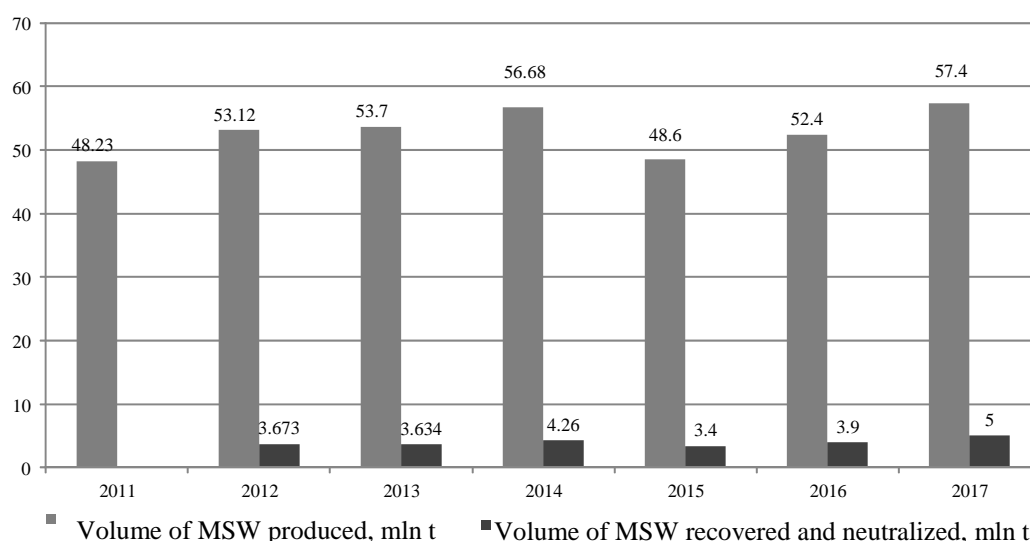


Figure. The dynamics of production and use of production and consumer waste.

Such regions as Sverdlovskaya Oblast and Permsky Kray have always been Russian industrial centers. Environmental degradation in these regions is aggravated by the presence of the facilities of accumulated environmental damage, appeared as a result of the economic activity in the past.

In the Middle Urals, the volume of MSW production exceeds 1.5 million tons per year. 80 million tons can be found at official landfills and disposal facilities only. The total area of disposal facilities in the country exceeds 40 thousand square kilometers. This is almost a third of the total area

of Sverdlovskaya Oblast. In Sverdlovskaya Oblast, the volume of MSW production in 2017 amounted to 1,760.5 th. tons. 163.1 th. tons were recovered and neutralized, which represented 9.3% (in 2016 it was 178.2 th. tons, representing 10.8%). In the region, as of the end of 2017, there are 786 operating and decommissioned, and 129 restored production and consumer waste disposal facilities. The total area occupied by municipal waste disposal facilities was 215.6 ha [8].

In 2018, 1,732 unauthorized disposal facilities were discovered in the regional municipalities, of which 1,438 had been eliminated by the end of the year; the total area of waste disposal is about 90 hectares. Last year, elimination of unauthorized disposal facilities reduced the discharge of about 6 kilograms of phenol and 4 tons of methane, hydrogen sulphide and ammonia into the air. The reform intends to eliminate all unauthorized disposal facilities within the territory of Sverdlovskaya Oblast by 2024, as well as to restore old landfills, and to build a modern, environmentally friendly infrastructure to be financed by budgetary and recruited sources of financing (comprised of at least 12 MSW processing complexes, 2 ecological technology parks, and recovery and burial facilities meeting the requirements of state standards GOST and Sanitary Rules and Regulations SanPiN).

778.3 million tons of production and consumer wastes have been accumulated within the Permsky Kray territory, which adversely impacts the environment and population. Most of the waste is disposed at the facilities with a long service life which are filled to more than 80%. The problem with waste disposal is most acute in rural settlements, where waste is accumulated at unauthorized facilities. In 2017, 1,445 unauthorized disposal facilities with a total area of more than 210.7 ha were identified within Permsky Kray, of which 32 sites with a total area of 1.3 ha are located within the water preserving zones of water bodies. 922 facilities were eliminated, which represents 63.8% of the total number of identified sites. Of the 32 identified sites of unauthorized waste dumping within water preserving zones, 22 facilities with a total area of 0.7974 ha have been liquidated. In 2017, efforts were made to prevent and to combat environmental violations. Thus, the sites with adverse impact on the environment were officially registered [9].

Today, waste burial in landfills is the most common waste recycling method in the world. This method is applied to non-combustible wastes, as well as to wastes that emit toxic substances during the combustion process.

Existing MSW burial facilities can be divided into three main categories:

Category 1 – fly-tipping. Such sites are not subjected to any engineering and environmental surveys that are usually carried out for the areas intended to waste disposal. They require minimal economic expenditures during their operation and after their closure. The waste is accumulated in bulk without compaction and isolation. The burial itself and its zone of influence are not subject to any control for a long period of time.

Category 2 – authorized unequipped MSW burial landfills. They meet the requirements of the standards for location of the facility according to sanitary and geological and hydrological criteria; when being disposed, the waste is compacted in layers, in some cases, without isolation of the layers. At the end of its service life, the facility is subject to final backfilling of the burial surfaces. There is no routine supervision of the landfill and the zone of its influence.

Category 3 – sanitary landfills, which are supposed to follow the storage technological process and monitor their impact on the environment. They are also supposed to be fitted with engineering constructions [10].

Recycling is carried out in order to reduce the amount of MSW disposed in landfills, to preserve natural resources and raw materials for the industries, methane emission reduction.

Long-term MSW burial facilities can be considered as reserves of the deposited secondary resources.

3. Justification of the use of MSW landfills

One of possible engineering solutions for the implementation of projects for the reburial of waste from old disposal facilities is excavation of the landfill body with further sorting and extraction of the soil and, in some cases, recycled materials. This will reduce the amount of waste subject to reburial.

This paper relies on the data from the Perm National Research Polytechnic University, the Department of Environmental Protection, and the calculations aimed at the restoration of the Municipal Waste Disposal Facility in the city of Berezniki; MSW disposal facility of the *AZOT* branch of *URALCHEM Group* (OAO); Municipal Waste Disposal Facility in the city of Dobryanka; disposal facility of Polazna urban-type settlement.

Comparison of the morphological compositions of wastes of different ages within Permsky Kray revealed an increase in the content of the landfill soil and a decrease in the content of biodegradable components as the period of their burial increases. The changes occurred in the course of time at the burial in terms of the proportion of fractions of biodegradable waste, such as paper, cardboard, wood, are primarily associated with the processes of waste decomposition in the landfill body. The 2–5-year landfill bodies are characterized by a 10–15% content of biodegradable components. The content of these waste fractions in 15-year-old landfills or older is reduced to 2–5 %. The proportional content of landfill soil in the wastes over 15 years old flattens out with increasing age of the waste and reaches an 80% limit. This is attributed to the high degree of decomposition of biodegradable components and the low content of polymer materials in the initial composition of the waste [11].

According to leading experts [12], the following excavation options can be distinguished:

- Waste excavation or collection at the outer border of a landfill to reduce its area, combined with the immediate placement, compaction and covering of the collected material with a layer of the soil on the remaining area.
- Excavation of all the wastes (at a small disposal facility) and transportation of the materials to an operating MSW landfill.
- Excavation of all the materials, temporary storage near a disposal facility, construction of a new landfill at the initial site in accordance with sanitary standards, and MSW burial at the new landfill.
- Excavation of materials, processing and recovery of reclaimed materials, modernization of the site and MSW burial at the new site.

It should be noted that there is no accepted international practice for provision of any standards or rules strictly classifying the indicated options or prescribing their application. Different countries, districts, cities and residential areas address the problem of MSW processing on a case-by-case basis with due regard to local conditions and contexts, financial possibilities and other factors. Therefore, every particular case involves different elements of the above-mentioned approaches and processes, depending on the tasks and objectives to be achieved.

The choice of a restoration process for a burial facility is influenced by many factors, including

- Location of the facility.
- Type of disposed waste and its properties (toxicity, aggregate state).
- Burial process (with or without compaction and isolation).
- Environmental impact.
- Proximity to settlements and many others.

The projects of the landfill excavation with the extraction of secondary resources are currently particularly valuable. These allow

- 1) Extracting secondary materials (polymers, glass, metals, etc.).
- 2) Extracting combustible fractions (polymers, wood).
- 3) Reducing the burden on the environment due to the removal of the waste body and restoration of the landfill territory.

The article examines several options for the implementation of the landfill restoration projects: 1) MSW landfill restoration in situ; 2) MSW landfill restoration with waste removal; 3) waste removal with the sampling of soil materials; 4) restoration with waste removal with a preliminary sampling of the soil and some types of secondary raw materials.

4. Environmental and economic analysis of the efficient use of MSW landfills

The main products of the waste recovery are

- 1) Secondary material resources (for example, ferrous and non-ferrous metals).
- 2) Waste fuel secondary components (polymer materials, paper, cardboard).
- 3) Land plot released during waste excavation.

To increase economic efficiency of the landfill restoration projects, biogas and extracted secondary materials can be sold, the land plot can be sold or leased out for further use.

The costs of these four restoration options for each landfill are given in Table 1.

Table 1. Total costs of the landfill excavation, thousand rubles

| Landfill | Area, ha | Option 1 | Option 2 | Option 3 | Option 4 |
|-----------|----------|----------|----------|----------|----------|
| Berezniki | 12.6 | 26,480 | 304,929 | 390,656 | 582,043 |
| Azot | 6.3 | 19,962 | 41,345 | 52,610 | 76,678 |
| Polazna | 1.75 | 9,812 | 11,910 | 15,160 | 22,119 |
| Dobryanka | 2.35 | 19,108 | 17,690 | 22,536 | 32,976 |

The table has been compiled by the authors.

The revenue from the sales of recycled materials, glass, polymers, metals, and land plots is recorded as income.

Incomes from the sales of recycled materials, glass, polymers, and metals (thousand rubles) can be calculated as per formula 1 (per 1 ha of land):

$$I = \frac{\sum (M * X_i) * C_i}{S}, \quad (1)$$

where M is waste mass located at a landfill after sorting, t.

X_i is the share of extraction of the i -th component.

C_i is the price per ton of the i -th component, th.rub./t.

S is the landfill area, ha.

The average cadastral value of one hectare of land according to the data of the Ministry of Estate Administration and Land Relations for Permsky Kray is 1,300 thousand rubles.

Table 2. Incomes from the sales of recycled materials and land plot

| Parameter | Berezniki | Azot | Dobryanka | Polazna |
|--|-----------|--------|-----------|---------|
| Waste mass, t | 231,000 | 29,050 | 8,400 | 12,600 |
| Incomes from the sales of recycled materials per 1 ha, th.rub. | 9,258 | 2,329 | 2,424 | 2,708 |
| Incomes from the sale of the land plot, th.rub. | 16,380 | 8,190 | 2,275 | 3,055 |

The table has been compiled by the authors.

The total economic benefit from landfill restoration is provided in Table 3.

Table 3. The economic benefit from the implementation of landfill excavation projects, th. rubles

| Landfill | Area, ha | Option 1 | Option 2 | Option 3 | Option 4 |
|-----------|----------|----------|----------|----------|----------|
| Berezniki | 12.6 | -10,100 | -288,549 | -374,276 | -449,012 |
| Azot | 6.3 | -11,772 | -33,155 | -44,420 | -53,815 |
| Polazna | 1.75 | -6,757 | -8,855 | -12,105 | -14,325 |
| Dobryanka | 2.35 | -16,833 | -15,415 | -20,261 | -25,004 |

The table has been compiled by the authors.

Given the low prices for the primary resources in Russia, projects for excavating landfills with the extraction of material and energy resources are economically inefficient or show low efficiency.

Environmental efficiency is determined with due regard to the charge for MSW disposal and environmental damage. The amount to be charged for waste disposal within the limits set to the natural resource user is calculated by multiplying respective charge rates, taking into account the hazard class of waste, by the mass of waste to be disposed and by summing up the resulting products as per types of waste. The charge rate for the disposal of waste hazard class 4 in 2018 is 663.2 rubles per ton. The NEI charge for waste disposal at four landfills is given in Table 4.

To determine the cost of environmental damage caused to the soil, the *Method for calculating the extent of damage caused to the soil as an object of environmental protection* is currently used (approved by the Order of the Ministry of Natural Resources and Environment of the Russian Federation No. 238 dated July 08, 2010) [13].

The value form of the amount of damage caused to the soil as an object of environmental protection is calculated as per formula (2):

$$\text{DAM} = \text{DAMPoll} + \text{DAMwaste} + \text{DAMdeter}, \text{ rub.} \quad (2)$$

where DAMpoll is environmental damage caused by chemical pollution of soil, rub.

DAMwaste is environmental damage caused by unauthorized production and consumer waste disposal, rub.

DAMdeter is environmental damage caused to the soil by illegal overlapping of the soil surface, as well as the soil body by artificial surfaces and (or) linear infrastructure facilities, rub.

The calculation results are given in Table 4.

Table 4. Calculation of the NEI charge and environmental damage to the soil caused by unauthorized production and consumer waste disposal

| Parameter | Berezniki | Azot | Dobryanka | Polazna |
|---|-----------|---------|-----------|---------|
| Mass of waste hazard class 4, t | 55,000 | 10,000 | 4,000 | 5,000 |
| NEI th.rub. | 36,476 | 6,632 | 2,653 | 3,316 |
| Mass of waste of the same hazard class, t | 330,000 | 41,500 | 12,000 | 18,000 |
| DAMwaste, th.rub. | 2,145,000 | 269,800 | 78,000 | 117,000 |

The table has been compiled by the authors.

The above-mentioned calculations make it possible to determine the overall environmental and economic efficiency of the implementation of landfill restoration projects (Table 5). The overall environmental and economic efficiency is defined as the ratio of environmental and economic benefit of the environmental protection measures to the totality of all additional costs incurred for its implementation. The value of the overall environmental and economic benefit is determined as the difference between benefits from implementation of the environmental protection measures and additional costs that accompany its achievement.

Table 5. Overall Environmental and Economic Efficiency, rub./rub.

| Landfill | Option 1 | Option 2 | Option 3 | Option 4 |
|-----------|----------|----------|----------|----------|
| Berezniki | 82.0 | 6.2 | 4.6 | 3.0 |
| Azot | 13.3 | 5.9 | 4.4 | 2.9 |
| Polazna | 7.5 | 6.4 | 4.5 | 3.0 |
| Dobryanka | 5.4 | 5.9 | 4.4 | 2.9 |

The table has been compiled by the authors.

Benefits from the implementation of environmental protection measures represent the totality of all positive results of economic and environmental nature expressed in the value form. Additional costs represent a total of the consumption of material and financial resources (economic expenses) and the monetary evaluation of the entire complex of adverse environmental consequences arising from the implementation of an environmental protection measure.

The calculations demonstrate that Option 1 of the landfill excavation in Berezniki is characterized by the greatest efficiency. This is primarily attributed to the fact that it has got the largest area and the largest amount of waste. The least efficient is Option 4 at the Polazna landfill as it has the smallest area and can accumulate only a small amount of waste.

5. Elaboration of an algorithm for the efficient use of MSW landfills

The data of the environmental and economic analysis of the landfill restoration projects enable us to elaborate an algorithm for the efficient use of the MSW landfills. The ultimate goal has to be taken into account, namely reduction of fugitive biogas and filtrate emission, minimization of the landfill environmental impact after its closure, acceleration of the waste stabilization, and reduction of the landfill assimilation duration. The initial data for the decision-making should include the data pertaining to the previous studies of the MSW and landfill management, consistent patterns of the formation of the resource potential and emissions of the landfills, as well as the data on practical implementation of the MSW landfill management processes. The validation of the decision and evaluation of its efficiency should be carried out only on completion of the collection and analysis of the initial data.

The algorithm of the landfill efficient use comprises the following stages:

Stage 1: Analysis of the component composition, rates of MSW accumulation and density at a landfill → Quantitative and qualitative indicators of the MSW analysis.

Stage 2: Evaluation of the resource potential and emission characteristics of a landfill → Directions for the development of the landfill management system.

Stage 3: Selection of one or several promising options of the MSW landfill use → Prospective plan(s) for MSW management at a landfill

Stage 4: Evaluation of the composition and mass of the output waste streams → Quantitative and qualitative indicators of the output waste streams.

Stage 5: Overall estimation of the efficiency of a landfill management option → Conclusions about the efficiency of a MSW landfill management scheme(s).

This algorithm for the evaluation of the MSW management system requires the following to be conducted first: field studies of the rates of accumulation, density, component composition and other MSW characteristics, analysis of the material flows, evaluation of the resource indicators and emission characteristics.

The data pertaining to mass, composition and properties of the initial MSW and expected waste flows after their processing allow us to elaborate an efficient waste landfill management system in general, namely to evaluate the efficiency of the neutralization and burial processes for separate flows, to calculate a required capacity of the equipment, the quantity and quality of the secondary raw materials and fuel, and to predict feasible emissions while burying wastes.

6. Conclusion

This study has yielded the following conclusions:

1) The studies of waste body excavation are still most acute. The problems of reclamation and feasibility of use of the stored wastes are followed by the assessment of the economic expenditures and feasibility of implementation of these projects in modern conditions.

2) Analysis of the waste management system within the territory of the Russian Federation, Sverdlovskaya Olbast and Permsky Kray in particular, revealed a number of important insights associated with waste management. One of the problems is associated with a large number of unauthorized waste disposal facilities, which provides the opportunity to conduct research aimed at finding its solution.

3) The wastes accumulated at the landfills represent a deposited resource with material and energy value. The data on fractional and morphological composition of the wastes can provide the basis for the elaboration of the projects for extraction of the secondary resources from the waste body or recovery of the old landfills.

4) A landfill management method should be selected in such a way so that to reduce uncontrolled biogas and filtrate emissions, to minimize the environmental impact of a landfill after its closure, to accelerate waste stabilization, and to reduce the duration of the facility assimilation by the environment.

References

- [1] Ellen MacArthur Foundation 2015 *Delivering the Circular Economy a Toolkit for Policymakers* [Digital source] Access mode: <https://www.ellenmacarthurfoundation.org>
- [2] Plastinina I, Teslyuk L and Dukmasova N 2018 Implementation of the Circular Economy Principles in Regional Solid Municipal Waste Management in the Russian Federation *The innovative development of the economy: research and practical and theoretical journal* **5** (47) 129–40
- [3] *Decree of the President of Russia No. 204 Concerning national goals and strategic objectives of the development of the Russian Federation for the period through to 2024 year* [Digital source] Access mode: <https://base.garant.ru/71937200/>
- [4] Berezyuk M, Rumyantseva A and Lapina A 2016 Municipal solid waste management in a new legislation: comprehensive approach *E3S Web of Conferences* **6** 1006
- [5] Berezyuk M, Rumyantseva A, Savchenko N and Rumyantseva E 2017 Modern technologies of processing municipal solid waste: investing in the future *IOP Conf. Series: Earth and Environmental Science* **72** 012015
- [6] Berezyuk M, Rumyantseva A and Rumyantseva E 2017 Environmental and economic analysis of the project for municipal solid waste management on the basis of modern technologies *Bulletin of Voronezh State Technical University. Economy and Management* **3** 31–8
- [7] *On the State and Environmental Protection of the Russian Federation in 2017* State report [Digital source] Access mode: http://www.mnr.gov.ru/docs/gosudarstvennye_doklady/
- [8] *On the Condition and Environment Protection in the Sverdlovsk Region in 2017* State report [Digital source] Access mode: <https://mprso.midural.ru/article/show/id/1084>
- [9] *Report Concerning the state of the Permsky Kray environment and its protection in 2017* [Digital source] Access mode: <http://www.permecology.ru>
- [10] *Information and technical reference book 17-2016 Disposal of production and consumer wastes* (published July 1, 2017)
- [11] Slyusar N, Zagorskaya Yu and Ilyinykh G 2014 Research of the fractional and morphological composition of wastes at the old landfills and disposal facilities *Bulletin of Perm National Research Polytechnic University Applied ecology Urban studies* **3** 31–8
- [12] Slyusar N 2016 Feasibility of extraction of the deposited resources from the municipal solid waste burial body *Bulletin of Perm National Research Polytechnic University Applied ecology Urban studies* **1** 63–77
- [13] Order of the Ministry of Natural Resources and Environment of the Russian Federation No. 238 dated July 08, 2010 (version dated April 25, 2014) *Concerning the approval of the Method for calculating the extent of damage caused to the soil as an object of environmental protection* [Digital source] Access mode: http://www.consultant.ru/document/cons_doc_LAW_104774/

Published under licence in Journal IOP Conference Series Earth and Environmental Science